Supplementation strategies for lactating dairy cows offered very high quality grass silages: starch-based or fibre-based concentrates offered with or without straw

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ABSTRACT

A three-period change-over design study using 24 mid-lactation multiparous Holstein-Friesian dairy cows, examined supplementation strategies for a high quality grass silage (dry matter (DM), 418 g/kg; crude protein (CP), 170 g/kg DM; metabolisable energy (ME), 12.1 MJ/kg DM). Four treatments, in a 2 × 2 factorial arrangement, compared concentrate type (High-starch or High-fibre) and straw inclusion (Straw or No-straw). Concentrates had a starch and neutral detergent fibre content of 373 and 258 g/kg DM, respectively (High-starch), and 237 and 339 g/kg DM, respectively (High-fibre). In the No-straw treatments, silage and concentrates were offered as a total mixed ration in a 57:43 DM ratio. In the Straw treatments, chopped straw was added at 4% of total DM, replacing part of the silage component of the diet. Following this study, the effect of diet on nutrient utilisation efficiency was examined using four cows/treatment. There were no interactions between concentrate type and straw inclusion for any cow performance or digestibility parameters. Silage dry matter intake (DMI) and total DMI were reduced with the High-fibre concentrate ($P = 0.001$ and $P = 0.006$, respectively) and straw inclusion ($P < 0.001$ and $P = 0.014$, respectively). Neither concentrate type nor straw inclusion had a significant effect on milk yield or milk fat content. The High-starch concentrate increased milk protein content ($P < 0.001$), while straw inclusion decreased milk protein content ($P = 0.036$). Treatment had no effect on cow body weight, condition score, faecal scores, digestibility coefficients or nitrogen and energy utilisation efficiency. In conclusion, supplementing a high quality grass silage with a carefully formulated 'high starch' concentrate improved DMI and milk protein content with no adverse effects on cow performance. Straw inclusion in the diet had no beneficial effects on DMI, milk production or nutrient utilisation efficiency.

KEYWORDS: Dairy cows; high quality grass silage; straw; concentrate energy source; fatty acids; ration digestibility

1. Introduction

Achieving high nutrient intakes is a key objective in the management of high yielding dairy cows. For housed cows managed within grassland based production systems, this can be achieved by improving the quality of the grass silage component of the diet, and/or increasing concentrate feed levels (Ferris et al., 1997; 2001). The benefits of increasing silage quality are well known, with a review by Keady et al. (2013) indicating that for each 10 g/kg increase in silage dry matter (DM) digestibility, DM intake (DMI) and milk yield are increased by 0.22 kg/day and 0.33 kg/day, respectively. In addition, the concentrate sparing effects of higher quality silages have been clearly demonstrated (Ferris et al., 2003).

A recent survey of silage making practices in Northern Ireland (NI) demonstrated that while 22.4% and 64.9% of farmers still adopt either a two or three harvest silage production system, a significant number (12.7 %) now adopt a 'multi-harvest' system (four or more harvests) in an attempt to improve silage feed value (Ferris et al., 2019). While anecdotal evidence indicates that the adoption of multi-harvest systems is increasing, concerns are often raised that highly digestible silages are not utilised efficiently by dairy cows. Earlier or more frequent harvesting reduces the fibre concentration of silages (Kuoppala et al., 2008; Randby et al., 2012), and the reduction in fibre could have a negative impact on rumen function and digestive efficiency (Mertens, 1997). This situation may be exacerbated if cows offered very high quality silages are supplemented with high levels of starch-based concentrates which may depress rumen pH, leading to acidosis, a reduction in fibre digestibility and decreased intakes (Martin et al., 1994: Keady et al., 1999). The compromised rumen function associated with high starch concentrates has been shown to reduce milk fat concentrations on both grass silage based diets (Keady et al., 1998; 1999) and grazed grass based diets (Sayers et al., 2003). Similarly, Boerman et al. (2015) offered a high quality maize silage based diet to high yielding cows (46 kg milk/cow/day), and found milk fat content and fat corrected milk yield to be reduced by 3.7

g/kg and 1.5 kg/day, respectively, when a starch-based concentrate was offered compared to a fibre-based concentrate. As a consequence, supplementing very high quality silages with more fibrous concentrates is often advocated. However, there are benefits of offering starch-based concentrates, including: increased milk protein concentrations (Keady et al., 1998), milk yields and DMIs (Boerman et al., 2015).

The addition of chopped straw to the diet of high yielding cows offered high quality silage is often advocated in the UK and Ireland to combat the negative effects of the lower fibre content of the silage. Straw inclusion in the diet is associated with increased retention time of digesta in the rumen (Nandra et al., 1993), which may allow other feed components to be more efficiently digested and absorbed. Neutral detergent fibre (NDF) is associated with chewing activity, increased cudding, and increased saliva production which in turn helps stabilise rumen pH (Welch and Smith, 1970). On the other hand, straw inclusion can reduce total DMI due to the high concentration of slowly fermentable carbohydrate (Van Soest, 1975). Indeed, there is little evidence that improvements in animal performance can be achieved by incorporating straw into the diets of dairy cows (Brown et al., 1990; Ferris et al., 2000), while high levels of straw inclusion (>1 kg/head/day) have been found to reduce animal performance due to dilution of the ME concentration of the diet (Ferris et al., 2000).

To date, no studies appear to have examined the interaction between concentrate type and straw inclusion in high quality grass silage based diets. In addition, given that modern dairy cow rationing programmes can account for fermentable energy and protein, the effectiveness of the fibre content of the diet, and predict the acid load in the rumen, it may be possible to design starch-based concentrates that can be offered as a supplement to a very high quality grass silage, without negative effects on rumen function, while still delivering the benefits of starch-based concentrates. Consequently, the current study was designed to examine the effect of

concentrate type (starch-based or fibre-based), and straw inclusion (straw or no straw), on cow performance and nutrient utilisation, when offered alongside a very high quality grass silage.

2. Materials and methods

This study was conducted at the Agri-Food and Biosciences Institute (AFBI), Hillsborough, Northern Ireland. All experimental procedures were conducted under an experimental licence granted by the Department of Health, Social Services & Public Safety for Northern Ireland in accordance with the Animals (Scientific Procedures) Act 1986.

2.1 Animals and housing

Twenty-four mid-lactation (mean of 149 (s.d. 52) days calved) multiparous (mean lactation number 3.8 (s.d. 1.2)) Holstein-Friesian dairy cows were used in a three-period, each of four weeks duration, partially balanced change-over design experiment involving four treatments. Each four-week period consisted of a 21 day feed adaption period, and a seven day measurement phase. Cows were blocked according to pre-experimental milk fat + protein yield into six blocks, each of four cows, and cows within each block randomly allocated to one of the four treatments. Cows had a mean pre-experimental milk yield and body weight (BW) of 37.3 (s.d. 5.4) kg per day, and 633 (s.d. 53.0) kg, respectively.

For the two week period prior to the study commencing, cows were offered a non-experimental grass silage supplemented with approximately 10 kg concentrate per day. Approximately half of the concentrate was offered mixed with the silage using a diet feeder, and half offered via an out-of-parlour feeding system (OPF). Three days prior to the start of the study, concentrates were removed from the OPF, with the full concentrate allocation mixed with the silage in the form of a total mixed ration (TMR) comprising 43% concentrate and 57% forage on a DM basis.

Throughout the 12 week experimental period cows were housed in a free-stall house with concrete flooring, and had access to individual cubicles that were fitted with rubber mats and bedded with sawdust. The cubicle-to-cow ratio was ≥1:1 at all times, thus meeting the recommendations of FAWC (1997). The floor area was cleaned every 3 hours using an automated scraper system.

2.2 Treatments

The four treatments were organised in a 2 × 2 factorial arrangement, comprising two concentrate types (High-starch or High-fibre) and two levels of straw inclusion (Straw or No-straw). A high quality grass silage was offered throughout the study (volatile corrected oven DM, 418 g/kg; CP, 170 g/kg DM (CP = N × 6.25); ME, 12.1 MJ/kg DM). The silage was produced from a perennial ryegrass (*Lolium perenne*) based sward. Grass was harvested using a precision-chop harvester on 3rd May 2017, following a 24 hour period of field wilting. Grass was treated at harvest with a bacterial inoculant (ULV50, Biotal, Malvern, UK) at approximately 20 ml per tonne of fresh herbage, before being ensiled in a bunker silo.

With the No-straw treatments, grass silage and concentrates were offered in the form of a total mixed ration (TMR) comprising 57% silage and 43% concentrate, on a DM basis. Concentrates were formulated and total rations balanced using NutriOpt (Nutreco, Amersfoort, Netherlands) dairy cow rationing software. While the two concentrates differed in NDF and starch content, they had a similar ME and CP content. The total rations were designed to promote rumen function and nutrient utilisation, and took account of a number of parameters, including acid load, structural fibre content and fermentable energy and protein balance. This approach was taken to reduce the common confounding factors encountered when comparing fibre and starch diets. The ingredient composition of the two concentrates is presented in Table 1.

With the Straw treatments, chopped barley straw was included in the diet at 4% of total DM, replacing part of the grass silage component of the diet. Straw was chopped with a Kverneland 850 bale chopper (Klepp, Norway) to a nominal chop length of approximately 5 cm (hand separation of a 10 g sub sample indicated that 5.6, 35.4, 20.9, 12.7, 9.5 and 6.4% of straw by weight had chop lengths of < 2 cm, 2 – 3 cm, 3 – 5 cm, 5 – 7 cm, 7 – 9 cm, 9 – 15 cm and > 15 cm, respectively).

The rations were prepared daily at approximately 09.00 hours, and offered *ad libitum* at 107% of the previous day's intake. Uneaten ration was removed the following day at approximately 08.00 hours. Rations were prepared using a mixer wagon (Vari-Cut 12, Redrock, Armagh, NI). The total quantity of silage required for all four treatments was initially mixed for approximately five minutes and then deposited on a clean silo floor. The quantity of silage required for each individual treatment was then removed from this 'pile' in turn, placed back in the mixer wagon, and the appropriate quantities of the concentrate and straw added to the mix, and mixing continued for another five minutes. The rations were then transferred from the mixer wagon to a series of feed boxes mounted on weigh scales, with cows accessing food in these boxes via an electronic identification system, thus enabling individual cow intakes to be recorded daily (Bio-Control Feeding System, Bio-Control, Rakkestad, Norway). Cows had free access to fresh water at all times.

2.3 Cow measurements

Feed intakes were measured as described above. All cows were milked twice daily (between 06.00 and 08.00 hours and between 15.00 and 17.00 hours) throughout the experiment using a 50-point rotary milking parlour (Boumatic, Madison, WI, USA). Milk yields were automatically recorded at each milking, and a total daily milk yield for each cow for each 24 hour period calculated. Milk samples were taken during four consecutive milkings at the end

of the fourth week of each period, treated with a preservative tablet (lactab Mark III, Thompson and Cooper Ltd., Runcorn, UK), and stored at 4°C until analysed (normally within 48 hours). Milk samples were analysed for fat, protein and lactose concentrations using an infrared milk analyser (Milkoscan Combifoss^{TM}7; Foss Electric, Hillerød, Denmark), and a weighted concentration of each constituent determined for each 24 hour sampling period. A mean composition over the two day sampling period was subsequently calculated for each cow.

A further milk sample was taken, in proportion to milk yield, during two successive milkings at the end of the final week of each experimental period. Samples were analysed for milk fatty acids (FA), as follows: milk fat was extracted from 1.0 ml of homogenised milk using a chloroform methanol extraction method (Bligh and Dyer 1959), and FA determined as methyl esters (FAME). The FA composition was determined using gas-liquid chromatography, with an aliquot (1.0 ul) of the FAME extract injected onto a CP Sil88 capillary column (100 meters x 0.25 mm id x 0.2 µm film thickness) in a Agilent 7890 gas chromatograph (both Agilent Technologies, Santa Clara, USA), equipped with a temperature programmable injector operated in the split mode and a flame ionisation detector. The oven was initially held at 50ºC for 4 minutes then ramped at 8ºC/min to 110ºC, then 5ºC/min to 170ºC (hold time 10 min) and finally ramped at 2ºC/min to 225 ºC (hold time 30 min). Fatty acids were identified by their retention time with reference to commercially available FA standards (37 Supelco FAME mix) and individual standards for those not in the mix (SigmaAldrich Co. Ltd., Gillingham, UK), and were quantified using C13 FAME as an internal standard.

Body weight was recorded twice daily during the final week of each experimental period (immediately after each milking) using an automated weighbridge, and a mean BW for each cow determined. The body condition score (BCS) of each cow was estimated by a trained technician at the end of the fourth week of each period, according to Edmonson et al. (1989) on a 5 point (including quarter points) scale. Blood samples were collected from the coccygeal

189 vein of each cow prior to feeding at the end of the fourth week of each period, and centrifuged
190 (3000 rpm for 15 minutes) to isolate either the serum (tubes with a clot activator) or the plasma
191 (fluoride oxalate tubes). Serum beta-hydroxybutyrate (βHB) concentrations were determined
192 according to McMurray et al. (1984), and plasma glucose concentrations were determined
193 using the hexokinase method (Roche Diagnostics Ltd.). Serum non-esterified fatty acid
194 (NEFA) concentrations were determined using WaKo (Wakop Chemicals GmbH, Neuss,
195 Germany) kits. Serum urea concentrations were analysed using the Kinetic UV method (Roche
196 Diagnostics Ltd., Burgess Hill, UK).

197 Faecal scores were assessed weekly during the experiment. Scoring was undertaken at a
198 consistent time (prior to morning feeding) when cows were lying, and then compelled to rise.
199 Scoring was on a scale of 1 – 5 as follows: 1) very watery 2) thin; when the faeces lands the
200 'splatter' goes a long way 3) ideal; forming a cowpat to a height of 2-3 cm 4) thick; well-
201 formed and stacked in rings or 5) firm; stiff balls of faeces (Hulsen et al., 2006).

202 *2.4 Nutrient utilisation*

203 On completion of the 12 week feeding study, four cows from each treatment (n = 16) were
204 selected for use in a nutrient utilisation study. Cows were selected from each treatment group,
205 with selected cows balanced for daily milk yield and BW. Cows were tied by the neck in
206 individual stalls, with stalls fitted with a rubber mat. Cows continued to access their
207 experimental rations from feed boxes at the front of each stall. Experimental rations were
208 offered *ad libitum* daily at 09:00 hours (+10% of previous day's intake). Uneaten food was
209 removed the following day at 08:00 hours. Cows had access to fresh water at all times via a
210 drinker located within each stall.

211 Measurement of nutrient utilisation commenced 24 hours after cows were placed in this
212 experimental byre, with a six-day total faeces and urine collection period. Faeces were

collected in a plastic collection tray (96 cm ×108 cm × 36 cm) placed behind each cow. Urine was collected into a 25 litre plastic container via a flexible plastic tube which was attached to a urine separation system. This was held in position over the vulva by attaching it using Velcro fasteners to a 'patch' which was glued (Bostik, Paris, France) either side of the cow's tail head. Approximately 300 ml of 50% sulphuric acid was added to each urine collection container daily to reduce ammonia losses. The total weight of faeces and urine produced during each 24 hour collection period was recorded, and a sample of each (5% by weight) retained for subsequent analysis. Faeces and urine samples were stored in a fridge (< 4^{o}C) and bulked on day 3 (day 1 - 3) and day 6 (day 4 - 6). During the nutrient utilisation study, cows were milked twice daily (06.30 and 16:30 hours) within the experimental cow byre. During this time milk samples were taken at each milking, bulked in proportion to yield for days 1 - 6, and subsequently analysed for gross energy (GE), and nitrogen (N) concentrations. Each bulked urine and milk sample was analysed for N concentrations, while a further sample of each was freeze-dried (Heto Lyolab 3000, Fisher Scientific, Loughborough, Leicestershire, UK) and analysed for GE concentrations using a bomb calorimeter (Parr 6400 Bomb Calorimeter, Moline, IL, USA). Similarly, a sample of the bulked faeces sample for each cow was analysed for N concentrations (fresh basis), while a subsample was dried at 85°C for 72 hours, and the dry sample analysed for acid detergent fibre (ADF), ash and GE concentrations.

2.5 Feed analysis

A sample of the grass silage offered was taken daily throughout the experiment and dried at 85°C for 18 hours to determine oven DM content. Twice a week a sample of grass silage was dried at 60^{o}C and dried samples bulked for each 14 day period, with the bulked sample milled through a sieve with 0.8 mm aperture, and analysed for NDF, ADF and ash concentrations. Each week a fresh silage sample was analysed using near infrared reflectance spectroscopy (NIRS) for ME concentration according to Park et al. (1998). A further fresh silage sample was

taken weekly and analysed for GE, N, pH, ammonia-N and volatile components. A sample of straw and each concentrate was taken weekly, and one sub-sample dried at 85°C for 24 hours to determine oven DM content. An additional sub-sample was dried at 60°C for 48 hours, bulked for each 14 day period, milled through a 0.8 mm sieve, and subsequently analysed for N, NDF, ADF, ash and GE. The concentrates were also analysed for starch concentrations.

During the nutrient digestibility study, feed stuffs where analysed for the same chemical components as during the main study. Silages were sampled daily and analysed for oven DM (85^{o}C), with fresh samples analysed for GE, N, pH, ammonia-N and volatiles. Dried samples were bulked for each 3-day period (day 1-3 and day 4-6), and subsequently analysed for ADF, NDF and ash concentrations. A sample of straw and each concentrate type offered during each nutrient digestibility study were sampled and analysed for oven DM (85^{o}C). A further sample was dried at 60^{o}C and subsequently analysed for GE, NDF, ADF, N, and ash concentrations. The concentrates were also analysed for starch concentrations. A sample of ration refused by each cow was taken daily and analysed for oven DM content. All chemical analysis of the feed stuffs offered where undertaken as described by Purcell et al. (2016).

2.6 Statistical analysis

Two cows did not complete period three due to health reasons (mastitis and oedema of the udder) and where subsequently treated as missing values during period three in the statistical analysis. Animal data recorded during the final week of each experimental period (DMI, milk yield, milk composition, BW, BCS, blood metabolites and faecal scores) were analysed using linear mixed model methodology according to the three-period change over experimental design, with constant + treatments as the fixed model, and block + block × cow + block × period as the random model. In all cases the method of residual maximum likelihood (REML) was used as the estimation method. One cow was removed from the nutrient utilisation study

due to mastitis. Data from the nutrient utilisation study was analysed using linear mixed model methodology with the REML estimation method. Period was fitted as a random effect and a factorial arrangement of Concentrate and Straw were fitted as fixed effects. If any of the fixed effects were significant ($P<0.05$) then Fisher's LSD Test was used to compare individual levels of the effects. All data were analysed using GenStat (18.1; VSN International Limited, Oxford, UK).

3.0 Results

The term 'high quality silage' in this paper encompasses both the intake potential of the silage and its nutritive value. The silage offered had a DM of 418 g/kg, a CP of 170 g/kg DM, and a predicted ME content of 12.1 MJ/kg DM. The High-starch and High-fibre concentrates had a similar CP and gross energy content, but differed in NDF (258 v. 339 g/kg DM) and starch (373 vs 237 g/kg DM) contents, as planned (Table 2).

3.1 Cow Performance

There were no interactions between concentrate type and straw inclusion for any of the parameters in Table 3, and as such only the main effects of treatment are presented. Both silage DMI and total DMI were reduced with the High-fibre concentrate ($P = 0.001$ and $P = 0.006$, respectively) and with straw inclusion in the diet ($P < 0.001$ and $P = 0.014$, respectively).

Neither concentrate type, nor straw inclusion had an effect on milk yield or milk fat content ($P > 0.05$) which averaged 33.1 kg/d and 45.0 g/kg respectively (Table 3). Cows offered the High-starch concentrate had a higher milk protein content than those offered the High-fibre concentrate ($P < 0.001$), while straw inclusion resulted in a reduction of milk protein content ($P = 0.036$). However, neither concentrate type nor straw inclusion had a significant effect on fat yield, protein yield, or fat + protein yield ($P > 0.05$).

285 The FA profile of the milk produced was unaffected by concentrate type, with the exception of
286 total concentrations of C4:0 - C15:0 (greater in the High-starch treatment, P = 0.004), C16:0
287 concentrations (greater in the High-fibre treatment, P = 0.037) and conjugated linoleic acid
288 (CLA; greater in the High-fibre treatment, P < 0.001). Concentrations of total saturated fatty
289 acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA)
290 were unaffected by concentrate type (Table 3). Straw inclusion decreased total C4:0 - C15:0
291 concentrations (P < 0.001) and C16:0 concentrations (P = 0.002), but increased concentrations
292 of C18:0 (P < 0.001), C20:0 (P < 0.001) and total n-9 PUFA (P < 0.001); however, there was
293 no effect of straw inclusion on CLA concentrations. Straw inclusion reduced the concentration
294 of SFA in milk and increased total MUFA concentrations (P < 0.001) compared to the No-
295 straw treatments, with a consequent reduction in the Saturated:Unsaturated FA ratio (P < 0.001)
296 in milk.

297 Treatment had no effect on either cow BW or BCS (Table 3; P > 0.05). Serum concentrations
298 of βHB and NEFA, and plasma concentrations of glucose, did not differ significantly between
299 treatments (average 0.43 mM, 0.12 meq/L and 3.61 mM, respectively: Table 4). Cows offered
300 the High-fibre concentrate had an increased serum urea content compared to those offered the
301 High-starch concentrate (P < 0.001). Straw inclusion tended to decrease serum urea
302 concentrations (P = 0.053). There was an interaction between concentrate type and straw
303 inclusion for serum urea, with mean values for High-starch/No-straw, High-starch/Straw,
304 High-fibre/No-straw and High-fibre/Straw being 3.13, 2.53, 3.16, 3.37 mM, respectively (SED
305 = 0.138; P < 0.001). Serum urea was higher when straw was offered with the High-fibre
306 concentrate, but not when straw was offered with the High-starch concentrate (P < 0.001). Diet
307 had no effect on mean faecal scores (average 2.6; s.d., 0.31).

308 *3.4 Nutrient Utilisation*

There were no significant interactions ($P > 0.05$) between concentrate type and straw inclusion in the diet for any of the nutrient utilisation parameters presented in Tables 5, 6 or 7, and consequently only the main effects of treatment are presented. Neither total DMI nor milk yields differed between treatments within the sub-group of cows used in the nutrient utilisation study ($P > 0.05$). Similarly, none of the digestibility coefficients examined were affected by treatment (Table 5).

Neither total N intake, nor N output in faeces, urine, manure or milk, were affected by concentrate type ($P > 0.05$; Table 6). When straw was included in the diet, cows had a lower N intake ($P = 0.009$) and a lower faecal N output ($P = 0.028$) compared to cows on the No-Straw treatment. None of the N use coefficients were affected by either concentrate type or straw inclusion in the diet ($P > 0.05$).

Neither GE intake, nor energy output in faeces, urine or milk were affected by treatment (Table 7). However, there was a trend ($P = 0.050$) for urinary energy output to be reduced when straw was included in the diet. None of the energy use coefficients were affected by either concentrate type or straw inclusion in the diet ($P > 0.05$).

4. Discussion

Grass silage is a major forage source for dairy cows in the more western parts of the UK and Ireland. In NI the average DM, CP and ME contents of commercial farm silages analysed by AFBI between 1996 – 2015 ($n > 90,000$ silages) were 280 g/kg, 123 g/kg DM and 10.7 MJ/kg DM, respectively (Yan et al., 2017). Thus the silage used in the current study (DM, 418 g/kg; CP, 170 g/kg DM; ME, 12.1 MJ/kg DM, Table 2) was of a much higher quality than the NI average, reflecting the early cutting date and rapid field wilting. The silage was also well fermented, as indicated by its low ammonia-N content and lactate dominated fermentation.

Within NI there has been an increasing move to multi-cut systems (>3 cuts/year) in an attempt to improve the quality of silages produced (Ferris et al., 2019), and consequently high quality silages, such as the one used in the current study, are likely to become more common on NI farms. This study was designed to examine supplementation strategies for high quality silages, to ensure optimum performance and high levels of nutrient use efficiency. On many farms current practice is to supplement very high quality silages with a fibre-based concentrate, or to add straw to the diet to help 'maintain rumen function', and thus reduce the likelihood of digestive upset or metabolic diseases. Within the current study there was no interaction between concentrate type and straw inclusion for any of the parameters examined (except for plasma urea), and as such concentrate type and straw inclusion are discussed separately.

Silage intakes in the current study were higher than those recorded in many previous studies (Rinne et al., 1999; Dewhurst et al., 2003; McNamee et al., 2015), although comparable intakes to those observed in the current study have been recorded by Randby et al. (2012) and Kuoppala et al. (2008) with highly digestible silages. Both digestibility (Huhtanen et al., 2007; Steen et al., 1998) and DM content (Steen et al., 1998) are key determinants of silage DMI. Steen et al. (1998) also found a positive correlation between silage protein concentration and silage DMI. Therefore, the very high intakes observed in this study are likely attributable to the high DM, CP and digestibility of the silage offered.

4.1 Effect of concentrate type

The impact of concentrate type on DMI has not been consistent. For example, Aston et al. (1994) and Huhtanen et al. (2008) found DMI to increase as the fibre concentrations of the concentrate increased, while Keady and Mayne (2001) found no effect of either a starch- or fibre-based concentrate on DMI. The reduction in DMI when high starch diets are offered is frequently associated with a depression in rumen pH, which may reflect subacute acidosis, a

356 consequence of high levels of rapidly fermentable carbohydrates with some starch-based diets
357 (Martin et al., 1994). However, in the current study DMI was 0.8 kg DM/day lower when the
358 High-fibre concentrate was offered (Table 3).

359 The higher DMI with the starch-based diet is likely to reflect, in part, the fact that the High-
360 starch concentrate offered was formulated using NutriOpt (Nutreco, Amersfoort, Netherlands)
361 to optimise rumen health by taking parameters such as 'acid load' and 'structural fibre index'
362 into consideration. The 'acid load' parameter within the NutriOpt rationing programme is
363 calculated based on total fermentation products, which includes both volatile fatty acid (VFA)
364 production in the rumen and silage fermentation products (e.g. lactic acid) consumed from the
365 diet. The 'structural fibre index' takes into account the effectiveness of dietary fibre to promote
366 rumination. An 'acid load' of less than 50 units and a 'structural fibre index' of greater than
367 100 units is considered ideal for rumen health when both parameters are considered together.
368 The High-fibre and High-starch diets had a predicted acid load of 47 and 50, respectively, and
369 a 'structural fibre index' of 108 and 104, respectively. Rations were also formulated taking
370 account of 'rumen unsaturated fatty acid load (RUFAL)'. Rumen fermentation is influenced
371 by RUFAL, which is determined as the sum C18:1, C18:2 and C18:3 FA. In a review, Walker
372 et al. (2004) indicated that these FA are associated with disruption to rumen fermentation and
373 with milk fat depression. Based on NutriOpt, the High-starch and High-fibre diets were
374 predicted to contain 21 and 20 g/kg DM RUFAL, respectively, with these values below the
375 maximum recommended level of 25 g/kg DM (NutriOpt). The absence of effects of concentrate
376 type on faecal scores, and on any of the digestibility and nutrient utilisation efficiency
377 coefficients suggest both concentrate types were associated with good rumen health. The
378 reduction in DMI with the High-fibre concentrate in the current study may have been due to
379 increased rumen fill causing greater satiety (Allen, 1995).

While concentrate type had no effect on milk yield, milk protein content was reduced by 0.8 g/kg when the High-fibre concentrate was offered (Table 3). A similar reduction in milk protein content with fibre-based concentrates has been observed previously with grass silage based diets (Ferris et al., 2000) and grazed grass based diets (Sayers et al., 2003; Gordon et al., 1995). The reduction in milk protein concentration with the High-fibre concentrate treatments is likely related to the lower DMI with this treatment, combined with increased rumen propionate production (Rook, 1979), and increased microbial protein synthesis (Sayers et al., 2003) in the High-starch treatment.

While starch-based concentrates are often associated with a reduction in milk fat concentrations (Keady et al., 1998; 1999), no such effect was observed in the current study. While this may appear to be surprising given the difference in concentrate fibre and starch levels, it likely reflects the fact that both diets were formulated to have similar 'structural fibre indexes'. Although milk fat content was unaffected by treatment, the milk FA profile differed (Table 3). *De novo* synthesis of FA (C4:0 - C15:0) was greater (0.8 g/100 g total FA) in the High-starch treatments compared to the High-fibre treatments, with these FA largely synthesised by chain elongation using acetate, which is driven by fibre in the diet (Grummer, 1991). Therefore, it might be expected that the High-fibre diet would have increased the synthesis of C4:0 - C15:0 FAs, as found previously (Boerman et al., 2015). While the increase in total C4:0 - C15:0 FA in the High-starch concentrate treatments is unexplained, the actual differences between treatments were relatively small. However, C16:0, which is partly synthesised *de novo* in the mammary glands was greater with the High-fibre diet (0.5 g/100 g total FA). Concentrations of CLA were greater (0.03 g/100 g total FA) when the High-fibre diet was offered. Conjugated linoleic acid is of interest due to possible human health benefits and is formed by the biohyrogenation of dietary linoleic acid (Griinari and Bauman, 1999). Despite the changes in

404 individual FA within the profile, there was no significant difference in total saturated or
405 unsaturated FA when cows where offered either a High-starch or a High-fibre concentrate.

406 That concentrate type had no effect on cow BW, BCS (Table 3), and blood metabolites (βHB,
407 Glucose and NEFA, Table 4)) recorded during each measurement period, suggests cows had a
408 similar energy status. Cows gained 94 kg BW (s.d. 24.7 kg) and 0.1 (s.d. 0.11) units of BCS
409 over the 12 week experimental period. While part of the former will can be attributed to 'gut-
410 fill' associated with the very high silage DMI, cows were undoubtedly in positive energy
411 balance throughout the study, a reflection of the high DMI observed. The higher serum urea
412 concentrations observed in cows offered the High-fibre concentrate, compared to the High-
413 starch concentrate, occurred despite the two concentrates having similar CP concentrations,
414 and may reflect the High-fibre diet providing less readily fermentable energy to support
415 microbial growth to utilise rumen ammonia. Nevertheless, the nutrient utilisation study
416 provided no evidence that concentrate treatments impacted on N utilisation efficiency, or
417 indeed on energy utilisation efficiency (Table 6 and 7).

418 Again, literature evidence on the impact of concentrate type on nutrient utilisation is mixed.
419 For example, some studies indicate increased apparent diet digestibility when high starch
420 concentrates are offered (Aston et al., 1994). Keady et al. (1999) reported that fibre
421 digestibility was reduced with increased starch content of the concentrate, the latter likely due
422 to a reduction of cellulolytic activity. The absence of an effect on fibre digestibility in the
423 current study may be due to the fact that the diet was offered as a TMR. Supporting this
424 suggestion, Keady et al. (1998) found no effect of starch level on fibre digestibility when
425 concentrates where offered in small amounts during the day. Furthermore, the apparent
426 digestibility of ADF was lower in the previous studies than the current study (<0.60 v. 0.76
427 g/g) which may indicate that the fibre fractions within the current study where more easily
428 digested as a whole.

429 *4.2 Effect of straw inclusion*

430 Straw inclusion reduced total DMI by 0.7 kg/day (Table 3). The inclusion of straw in the diet
431 will increase rumen retention time and reduce the rate of passage of digesta through the
432 digestive tract leading to satiety and reduced DMI (Nandra et al., 1993). Despite the reduction
433 in DMI, milk yield was not significantly affected by straw inclusion, although milk protein
434 content was reduced by 0.4 g/kg with the straw treatments (Table 3). The latter is likely due to
435 the dilution of ME in the diet when straw is included, in agreement with previous studies (Blair
436 et al., 1974; Ferris et al., 2000).

437 Milk fat content was unaffected by straw inclusion to the diet, which agrees with the findings
438 of Ferris et al. (2000), who offered straw at levels between 0 – 3 kg/cow/d. In contrast, Owen
439 et al. (1969) and Blair et al. (1974) observed an increase in milk fat content with the addition
440 of milled straw to the diet (at 24% and 47.5% of the total diet); however, the overall diets
441 offered and straw inclusion levels adopted were very different from those in the current study.
442 The concentrates offered in the current study were balanced to contain optimum levels of
443 structural fibre, and this may have negated any possible effects of straw inclusion on milk fat.
444 Although milk yield was unaffected by straw inclusion, both milk fat yield and milk protein
445 were reduced, with this due to the numerically lower milk yield (0.8 kg/d) and milk fat content
446 (0.5 g/kg), and significantly lower protein content (0.4 g/kg) with the straw treatment.

447 As straw inclusion was expected to promote rumen acetate production, and *de novo* FA
448 synthesis, the increasing concentrations of C4:0 - C15:0, C16:0 with the No-straw treatment
449 was unexpected (Table 3). The C18:0, C18:1 and C20:0 fats in milk are mostly derived from
450 stearic acid in the diet (Moate et al., 2008), and their higher concentrations with the straw
451 treatment reflects the fact that straw contains a high proportion of stearic acid (42% of total
452 FA; Tyagi et al., 2010). In general, straw inclusion resulted in a small improvement in the fatty

453 acid profile of the milk which could be considered as beneficial concerning human health
454 (Vafeiadou et al., 2015), as the concentrations of SFA decreased and concentrations of MUFA
455 increased.

456 There was no effect of straw inclusion on BW or BCS (Table 3), while serum βHB and NEFA,
457 and plasma glucose concentrations, all of which can provide an indication of energy status,
458 were also unaffected (Table 4). The tendency (P = 0.053) for a reduction in serum urea
459 concentration when cows were offered straw reflects the dilution of total diet protein content
460 associated with straw. However, the interaction between concentrate type and straw inclusion
461 suggests that a starch-based concentrate promoted a rumen environment that was more
462 effective at utilising rumen ammonia, while the reverse occurred when straw was offered
463 alongside a fibre-based concentrate.

464 Surprisingly, straw inclusion had no effect on faecal scores or digestive efficiency during the
465 nutrient utilisation study. Ferris et al. (2000) observed that the inclusion of increasing levels of
466 straw in the diet actually decreased the digestibility of DM, N and energy, although the highest
467 inclusion level in that study, was considerably higher than in the current study (3 kg/cow/d).
468 While straw inclusion may have been expected to improve nutrient utilisation by stabilising
469 the rumen environment and reducing the rate of passage of digesta, nutrient utilisation was not
470 improved in either the study by Ferris et al. (2000) or the current study (Table 5). Total N intake
471 was reduced when straw was included in the diet within the nutrient utilisation study, a
472 consequence of the lower DMI observed and the low protein content of straw, and this was
473 associated with a corresponding reduction in output of faecal and manure N (Table 6).
474 However, this did not impact on N utilisation efficiency, perhaps due to a reduction in the
475 ability of rumen bacteria to capture ammonia due to straw inclusion in the diet. There was also
476 a trend for reduced energy intake when straw was offered and a corresponding decrease in

urinary energy, but no impact on faecal, urine or milk energy as a proportion of GE intake (Table 7).

The results of this experiment have a number of practical implications. For example, this study has demonstrated that modern dairy cow rationing programs can be used to formulate a high starch concentrate which can be used to supplement a very high quality grass silage, with no adverse effects on performance, while actually promoting intakes and milk protein content. In addition, this can be achieved with moderate yielding cows without the need to include straw in the diet. While there may have been an expectation that that supplementing a starch-based concentrate with straw would improve digestibility while maintaining intakes, and supplementing a fibre-based concentrate with straw would reduce intakes and milk yield, the absence of interactions in this study does not support these expectations. Furthermore, in common with the findings of earlier research, this study has failed to demonstrate any practical benefits of including straw in dairy cow diets, irrespective of concentrate type, provided that the concentrate fraction of the diet is designed appropriately and the diet is offered as a total mixed ration.

5.0 Conclusion

In the present study, neither concentrate type nor straw inclusion had a significant impact on milk yield or milk fat + protein yield. A High-starch concentrate, increased DMI and milk protein content compared to a High-fibre concentrate, and had no negative effects on faecal scores or nutrient utilisation when offered alongside a high quality silage. Straw inclusion reduced DMI and milk protein content, and had no beneficial effect on milk fat content or nutrient utilisation. Therefore, there is little evidence that straw inclusion in the diet of dairy cows is beneficial, and a carefully formulated High-starch diet can be fed alongside a high quality silage, without the use of straw as an additional fibre source.

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634 1996 to 2015 using data from the Hillsborough Feeding Information System -
635 regression between silage nutritive value and harvesting year. In: Proceedings of the
636 Annual Meeting of the British Society of Animal Science, p76, Chester, UK.

637 Table 1: Ingredient composition of the High-starch and High-fibre concentrates offered (%,

638 fresh basis).

	High-starch	High-fibre
Maize meal	54.2	22.7
Wheat		10.9
Soyabean meal (high protein)	4.5	5.9
Rapeseed meal	4.5	4.4
Soya hulls (toasted)	11.3	18.2
Sugar beet pulp (dry)	9.0	19.1
Maize gluten	9.0	11.4
Protected protein (Sopralin[a])	4.5	2.7
Protected fat (Maxfat CS[a])		1.8
Mineral/Vitamin mix (Maxcare Dairy[a])	1.8	1.8
Rumen buffer (Acid Guard[a])	1.1	1.1
Yeast (Actisaf[b])	0.1	0.1

639 [a] Trouw Nutrition, Belfast, Northern Ireland,UK
640 [b] Lesaffre, Marcq-en-Baroeul , France

641 Table 2: Chemical composition of the grass silage, concentrates and straw offered during the 12 week experimental period.

	Grass silage	(s.d)	Concentrates				Straw	(s.d)
			High-starch	(s.d)	High-fibre	(s.d)		
Oven dry matter (g/kg)	404	(23.4)	891	(15.8)	898	(13.8)	859	(29.6)
VCODM (g/kg)	418	(24.3)						
Crude protein (g/kg DM)	170	(7.0)	163	(3.8)	164	(1.7)	34	(0.6)
Ash (g/kg DM)	95	(1.8)	69	(3.8)	76	(4.3)	44	(7.2)
Acid detergent fibre (g/kg DM)	237	(3.6)	112	(8.0)	169	(6.8)	528	(0.3)
Neutral detergent fibre (g/kg DM)	364	(7.7)	258	(13.6)	339	(15.4)	864	(0.4)
Starch (g/kg DM)			373	(12.4)	237	(8.9)		
Gross energy (MJ/kg DM)	19.8	(2.85)	18.0	(0.09)	18.0	(0.10)	18.8	(0.01)
Metabolisable energy[a] (MJ/kg DM)	12.1	(0.21)						
pH	4.2	(0.07)						
Lactic acid (g/kg DM)	83	(4.1)						
Acetic acid (g/kg DM)	8.4	(1.91)						
Ethanol (g/kg DM)	11.4	(4.90)						
Ammonia (g/kg total N)	60	(8.7)						

642 [a] Predicted using NIRS; VCODM: Volatile corrected oven dry matter

643 Table 3: Effects of concentrate type and straw inclusion on the feed intake, milk production
644 and composition, the fatty acid content of milk, and body tissue reserves as measured during
645 final week of each experimental period.

	Concentrate type		Straw inclusion			P-Value	
	High-starch	High-fibre	No-straw	Straw	SED	Concentrate	Straw
Silage DMI (kg/d)	14.7	14.2	15.1	13.7	0.21	0.001	<0.001
Concentrate DMI (kg/d)	10.9	10.7	10.9	10.7	0.16	0.027	0.114
Total DMI (kg/d)	26.1	25.3	26.0	25.4	0.37	0.006	0.014
Milk yield (kg/d)	32.9	33.3	33.5	32.7	0.82	0.562	0.161
Fat (g/kg)	44.9	45.0	45.2	44.7	0.77	0.879	0.319
Protein (g/kg)	38.1	37.3	37.9	37.5	0.29	<0.001	0.036
Lactose (g/kg)	46.7	46.8	46.7	46.7	0.26	0.822	0.999
Fat yield (kg/d)	1.46	1.49	1.51	1.44	0.042	0.398	0.035
Protein yield (kg/d)	1.25	1.24	1.27	1.22	0.026	0.635	0.023
Fat+protein yield (kg/d)	2.71	2.73	2.77	2.66	0.064	0.692	0.403
Milk FA concentrations (g/100g total FA identified)							
Total C4:0 to C15:0	29.4	28.6	29.4	28.6	0.23	0.004	<0.001
C16:0	37.0	37.5	37.7	36.8	0.36	0.037	0.002
C18:0	8.4	8.4	8.0	8.7	0.17	0.749	<0.001
C18:1*cis*-9	16.7	16.9	16.3	17.3	0.29	0.259	<0.001
CLA,18:2*cis*-9, *trans*-11	0.43	0.46	0.44	0.45	0.010	<0.001	0.117
C18:2*cis*-9, *trans*-12	1.7	1.8	1.6	2.0	0.13	0.970	0.144
C20:0	0.13	0.14	0.13	0.14	0.003	0.455	<0.001
Total Saturated	74.6	74.3	74.9	73.9	0.43	0.399	0.002
Total MUFA	20.3	20.5	20.0	20.9	0.31	0.461	<0.001
Total PUFA	3.1	3.0	3.0	3.1	0.16	0.104	0.316
Total n-3 PUFA	0.8	0.8	0.8	0.8	0.02	0.199	0.084
Total n-6 PUFA	2.3	2.2	2.2	2.3	0.14	0.960	0.165
Total n-7 PUFA	2.4	2.3	2.3	2.3	0.06	0.341	0.492
Total n-9 PUFA	16.7	17.0	16.3	17.4	0.29	0.263	<0.001
Saturated:Unsaturated ratio	3.2	3.2	3.3	3.1	0.04	0.672	<0.001
Body weight (kg)	679	680	681	678	4.3	0.828	0.605
Body condition score	2.3	2.3	2.3	2.3	0.02	0.236	0.126

646 DMI, dry matter intake; FA, fatty acids, MUFA, monounsaturated fatty acids, PUFA poly-unsaturated
647 fatty acids
648

649 Table 4: Effects of concentrate type and straw inclusion on the blood metabolites of dairy cows

	Concentrate type		Straw inclusion			P-Value	
	High-starch	High-fibre	No-straw	Straw	SED	Concentrate	Straw
Serum BHB (mM)	0.51	0.35	0.50	0.35	0.227	0.295	0.345
Plasma glucose (mM)	3.65	3.57	3.62	3.61	0.055	0.065	0.665
Serum NEFA (mM)	0.12	0.12	0.12	0.12	0.018	0.759	0.726
Serum urea (mM)[a]	2.83	3.27	3.14	2.95	0.138	<0.001	0.053

650 [a] There was an interaction between concentrate type and straw inclusion for serum urea, with mean values for
651 High-starch/No-straw, High-starch/Straw, High-fibre/No-straw and High-fibre/Straw being 3.13, 2.53, 3.16, 3.37
652 mM, respectively (SED = 0.138; $P < 0.001$).

653 βHB, beta-hydroxybutyrate; NEFA, non-esterified fatty acids

654

655 Table 5: Effects of concentrate type and straw inclusion on dry matter intake and milk yield

656 during the nutrient utilisation study, and on total ration digestibility coefficients.

	Concentrate type		Straw inclusion			P-Value	
	High-starch	High-fibre	No-straw	Straw	SED	Concentrate	Straw
Silage DMI (kg/d)	12.5	12.5	13.4	11.5	0.58	0.825	0.007
Concentrate DMI (kg/d)	9.9	9.9	10.4	9.5	0.47	0.865	0.078
Total DMI (kg/d)	22.8	22.8	23.8	21.8	1.08	0.885	0.885
Milk yield (kg/d)	26.8	27.6	28.2	26.3	1.90	0.754	0.356
Digestibility coefficients (g/g)							
Dry matter	0.749	0.737	0.748	0.738	0.0119	0.291	0.406
Organic matter	0.748	0.742	0.749	0.740	0.0134	0.630	0.507
Nitrogen	0.604	0.601	0.600	0.605	0.0188	0.855	0.755
Gross energy	0.744	0.741	0.748	0.737	0.0138	0.720	0.441
ADF	0.757	0.757	0.769	0.755	0.0130	0.459	0.303
NDF	0.716	0.737	0.730	0.723	0.0151	0.185	0.621

657 DMI, dry matter intake; ADF, acid detergent fibre; NDF, Neutral detergent fibre

658

659 Table 6: Effect of concentrate type and straw inclusion on nitrogen (N) intake, nitrogen output

660 and nitrogen utilisation efficiency of dairy cows.

	Concentrate type		Straw inclusion			P-Value	
	High-starch	High-fibre	No-straw	Straw	SED	Concentrate	Straw
N intake/output (g/d)							
Total N intake	574	599	622	551	27.1	0.479	0.009
Faecal N	225	236	246	216	14.1	0.533	0.028
Urine N	158	176	170	164	11.3	0.124	0.587
Manure N	384	411	415	380	16.8	0.157	0.054
Milk N	154	155	162	146	9.5	0.978	0.122
N utilisation (g/g)							
Faecal N/N intake	0.396	0.399	0.400	0.395	0.0188	0.855	0.755
Urine N/N intake	0.280	0.297	0.276	0.300	0.0196	0.299	0.234
Manure N/N intake	0.676	0.695	0.675	0.695	0.0196	0.267	0.370
Milk N/N intake	0.271	0.262	0.264	0.270	0.0127	0.510	0.645
Faecal N/manure N	0.587	0.573	0.593	0.567	0.0236	0.466	0.293
Urine N/manure N	0.413	0.427	0.407	0.433	0.0236	0.466	0.293

661

662 Table 7: Effect of concentrate type and straw inclusion on energy intake, energy output and

663 energy utilisation efficiency in dairy cows.

	Concentrate type		Straw inclusion			P-Value	
	High-starch	High-fibre	No-straw	Straw	SED	Concentrate	Straw
Energy intake and output (MJ/d)							
GE intake	407	416	429	393	19.3	0.752	0.086
Faecal energy	103	106	106	102	6.2	0.637	0.404
Urinary energy	13	14	15	13	0.7	0.107	0.050
Milk energy	95	99	101	94	5.6	0.510	0.285
Energy utilisation (MJ/MJ)							
Faecal E/GEI	0.256	0.259	0.252	0.263	0.0138	0.720	0.441
Urine E/GEI	0.033	0.035	0.034	0.034	0.0016	0.108	0.613
Milk E/GEI	0.238	0.242	0.237	0.243	0.1172	0.652	0.592

664 GE, gross energy; E, energy; GEI, gross energy intake